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**ANALYSIS OF THE FAILURE OF FIBERGLASS FABRIC
REINFORCED SILICONE RUBBER CIRCULAR PRESSURE
RELIEF DUCT EXPANSION/CONTRACTION JOINT SEALS
AT PICKERING NGS UNIT 6 AND UNIT 7 DURING
THE 1990 AS FOUND PRESSURE TEST**

Report No. 90-172-K

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Abstract

In order to analyse the failures at the factory splices of the fiberglass fabric reinforced silicone rubber pressure relief duct expansion/contraction joint seals at Pickering NGS Unit 6 and Unit 7 during the 1990 as found pressure test, tensile test specimens were cut from the Unit 6 and Unit 7 seals in the longitudinal direction so that half the specimens contained the factory splice and half contained no splice. The specimens were tested for durometer hardness and then tensile tested to destruction. In addition, tensile and hardness tests were performed on a similar specimen of polyester fabric reinforced silicone rubber replacement seal material. Tests showed that the factory splice on both Unit 6 and Unit 7 seals had only 20% of the strength of the non spliced material indicating the presence of subsurface manufacturing induced flaws in the fiberglass fabric at the factory splices in Unit 6 and 7 seals. Tests also

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showed that the silicone rubber from both the Unit 6 and Unit 7 seals had a greatly decreased elongation at failure which could have led to rupture at the fabric flaws in factory splice. Comparison of results with the replacement seal material showed that the replacement seal material has approximately eight times the strength of the factory splices and eighty times the elongation, indicating the superiority of the replacement seal material.



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EXECUTIVE SUMMARY

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R.J. Lewak

During the as found pressure test of the Pickering NGS pressure relief duct (PRD) during the may 1990 Pickering NGS vacuum building outage, three failures occurred in the fiberglass fabric reinforced silicone rubber contraction joint seals. One of the failures occurred in the corner of a rectangular seal. This type of failure has been analysed previously. Two of the failures occurred in the factory splices of the circular joint seals at Unit 6 and Unit 7. Since no previous failures in these seals had occurred at a factory splice in a circular seal, an analysis of the failure mechanism in the Unit 6 and Unit 7 seals was required. To perform this analysis dumbbell shaped tensile test specimens were cut from both the Unit 6 and Unit 7 seals so that half contained the factory splice and half were of unspliced material. Durometer hardness tests were taken on these specimens which were then tensile tested to destruction. It was found that for both the Unit 6 and Unit 7 seals that the splice specimens had only 20% of the tensile strength of the non spliced specimens. Such a decrease in strength could be caused by a manufacturing induced subsurface flaw in the fiberglass fabric which had been isolated as the cause of the previous failures of this material. It was also found during the tensile tests that specimens from both seals exhibited low values of rubber elongation at break. This loss in elasticity of the silicone rubber was unexpected over such a short aging period under the PRD environmental conditions. Since in a flawed area such as the factory splices in Unit 6 and Unit 7 seals much of the stress during a pressure test must be taken by the rubber, a loss of elasticity of the rubber could lead to failure at this point in time but the rubber may have had a enough elasticity at the factory splice at a previous time to sustain a PRD pressure test.

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A tensile test was also performed on the replacement seal material of polyester fabric reinforced silicone rubber in a similar manner. Comparison between materials showed that the polyester fabric seal had twice the strength of the fiberglass fabric seal without a splice. Since the splice strength of the polyester fabric seal is specified at 90% of the unspliced strength, the polyester fabric seal splices will be eight times as strong as the fiberglass fabric splices. In terms of ultimate elongation which describes seal flexibility, the polyester fabric seal material has twenty times that of the fiberglass fabric seal material of Unit 6 and Unit 7. Therefore the replacement polyester fabric reinforced silicone rubber material is far superior to the old fiberglass fabric reinforced silicone rubber seal material used for the contraction joints at Unit 6 and Unit 7.

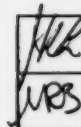

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To: Mr. R. Jeppesen
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1.0 INTRODUCTION

During the as found pressure test of the Pickering NGS pressure relief duct (PRD) during the May 1990 Pickering NGS vacuum building outage, three failures occurred in the fiberglass fabric reinforced silicone rubber expansion/contraction joint seals. One of the failures occurred in the upper north corner of the rectangular contraction joint seal 44. This type of failure has been encountered and analysed before. Two of the failures occurred in two circular seals, one in the seal at contraction joint 78 joining the Unit 6 bulkhead to the PRD and one in the seal at contraction joint 79 joining the Unit 7 bulkhead to the PRD. Since failures in circular seals during any pressure test had never been encountered before, a failure analysis was performed to determine whether or not the failure mode was similar to that encountered previously in these fiberglass fabric reinforced silicone rubber seals [1] which has led to the replacement of all of these seals during the outage.

This report details the examination of the failed areas of the Units 6 and 7 joint seals. In addition, samples of material from Units 6 and 7 in the failed area and other areas were tested for tensile strength and hardness along with the new polyester fabric reinforced silicone rubber seal material in order to determine the relative strength and flexibility of the old seal as compared with the new.

2.0 SEAL INSPECTION

Following the failures of the Unit 6 and Unit 7 seals, the seals were removed to a storage bay for contamination testing. Unfortunately, these two seals were not observed *in situ* in the PRD duct. The Unit 6 seal is shown in Figure 1. There was a rupture located in the factory splice approximately 8 cm long running in the transverse direction. This would indicate failure in the longitudinal direction. A close-up of the rupture is shown in Figure 2. The even edges of the cover rubber indicate a brittle failure of the rubber. The Unit 7 seal is shown in Figure 3. In the Unit 7 seal the rupture is also located in the factory splice approximately 11 cm long also running transversely indicating failure in the longitudinal direction. A close-up of the rupture is shown in Figure 4. Visual comparison with the rupture in the Unit 6 seal indicates a similar type of failure between Unit 6 and Unit 7.

Both the Unit 6 and Unit 7 seals had subsurface flaws in the fiberglass fabric which have been described in a previous report [1]. The cause of these flaws was the thermal stresses produced during the curing process of these seals in the factory. In general, it was shown that a flaw area had only approximately 10% of the strength in the longitudinal direction as unflawed material. Both Unit 6 and Unit 7 seals had flaws of this type on either side of the ruptures at the factory splices. This could indicate that the factory splices may have contained these types of flaws but are masked by the additional rubber added during the making of the splice.

As the above information was the only information which could be obtained from visual inspection, the seals were examined for radioactive contamination, cleaned, and transported to the Research Division facilities in Toronto.

3.0 LABORATORY TEST RESULTS

Four dumbbell shaped tensile test specimens were cut in the longitudinal direction from the Unit 6 seal and five dumbbell shaped tensile specimens cut in the longitudinal direction from the Unit 7 seal. Two specimens from each seal were cut from either side of the rupture so that they contained the factory splice at their midpoint. Specimens from the Unit 6 seal were designated Specimens C and D. Specimens from the Unit 7 seal were designated 1 and 2. Two other specimens, designated A and B, were cut from the Unit 6 seal and three specimens, designated 3, 4, and 5, cut from the Unit 7 seal a few centimeters away from the other specimens so that they would not contain the splice. In addition a specimen was cut from the polyester fabric reinforced silicone rubber seal material which is being used to replace the Pickering NGS PRD seals. The dimensions of the specimens are: gauge length of 15.6 cm nominal, width of end tabs

of 2.54 cm and a width in the test part of 1.2 cm nominal. The material thickness is 4.5 mm for the Unit 6 and 7 test specimens and 5 mm for the new seal specimen.

Prior to the tensile tests all the specimens were given a durometer hardness test using a Shore A hardness tester. Hardness tests were performed in accordance with ASTM 2240.

The specimens were then tensile tested to destruction using a JJ INSTRUMENTS T5K tensile testing machine with self locking and aligning jaws. The elongation of each specimen and the force required to produce this elongation was recorded. The elongation speed was 1 mm/min for the Unit 7 specimens and specimens B, C, and D. This elongation speed gives a strain rate of 0.6%/min. for these specimens' gauge length. Specimen A and the new seal specimen used a speed of 8 mm/min or a strain rate of 5%/min which is specified in the seal material specification. It was found, however, that a speed of 8 mm/min was too fast for the recording of the lower strains of fiberglass reinforced material.

3.1 Test Results

The hardness tests indicated that the average Shore A hardness for both the Unit 6 and Unit 7 seal specimens was 72 for most of the material but 55 for the area of splicing. This is no doubt due to the softness of the rubber used in the splice area, namely room temperature vulcanized (RTV) rubber. Since the specified hardness of the rubber before installation was in the order of 55 to 60, it appears that the rubber has significantly hardened over the 10 years since installation of the seals. The Shore A hardness of the new seal material was measured as 62 which is within the specified limits.

The test results for the Unit 6 specimens, A, B, C, and D are shown in the form of stress-strain curves in Figures 5 and 6. The test results for the Unit 7 specimens, 1 to 5, are shown in similar form in Figures 7 to 11 and the stress-strain curve for the new polyester reinforced seal material is shown in Figure 12.

4.0 DISCUSSION OF RESULTS

The results from the Unit 6 specimens show that the splice specimens have, on average, 22% of the strength of the non-splice specimens. This result is consistent with the presence of a flaw in the fiberglass fabric at the factory splice similar to flaws in the fiberglass fabric described in [1]. The results from the Unit 7 specimens show that the splice specimens have, on average, 23% of the strength of the non-splice specimens. Therefore, a flaw similar to that described in [1] should also be present in the Unit 7 seal factory splice.

Previous failures of fiberglass fabric reinforced silicone rubber seals had occurred in flawed areas which were located in the corners of the rectangular PRD seals from a combination of high stresses in the corner section combined with the low strength of the flawed areas. The flaw areas have very little, if any, contribution in strength from the fabric and rely on the rubber strength and flexibility. The low elongation values from the test results show that the flexibility of the silicone rubber in these seals has decreased dramatically with time. It is conceivable that the ruptures in the Unit 6 and Unit 7 seals during the May 1990 as found pressure test of the PRD occurred at this time and not during previous pressure tests because the rubber could not sustain the pressure test stress any longer due to this aging effect. The primary cause of the ruptures, of course, are the flaws in the fiberglass fabric which necessitated the silicone rubber to take the load caused by the pressure test. Since the flaws have existed in the seals since manufacture it is evident that the rubber was able to stand the previous pressure test stresses. A decrease in elongation and flexibility of the silicone rubber to this extent, over such a short time period under the conditions in the PRD, could not be anticipated.

A secondary cause of failure, which was hinted at in the results of the previous study [1], is that the application of stress weakens the already low strength of the manufacturing flaws in the fiberglass fabric. Therefore, it is not inconceivable that previous pressure tests in the PRD weakened the fiberglass fabric flaws in the factory splices so that failure occurred in the May 1990 as found pressure test. This weakening due to repeated stress is not at all understood at this time and any contribution to the failure in the Unit 6 and Unit 7 seals is conjecture. However, this phenomenon may also explain why the Unit 6 and 7 seals passed previous pressure tests and then failed in 1990.

Comparing the results of the Unit 6 and Unit 7 seals with the results off the new polyester fabric reinforced silicone rubber replacement seal material, it can be seen that the new material is superior in all respects to the old seals. Fabric failure in the new seal occurs at 19 MPa at a 37% strain and rubber failure at an elongation of 316%. The Unit 6 specimens show a fabric failure at an average of 10.3 MPa for the unspliced specimens and a fabric failure at 2.3 MPa for the spliced specimens. Elongation at break for the splice specimens is an average 3.7% and for the unspliced specimens is an average 16%. Therefore, the new seal material is almost twice as strong as the unspliced fiberglass fabric seal and eight times as strong as the factory splice in the fiberglass fabric seal in Unit 6. Furthermore, the elongation of the new seal material is 20 times that of the fiberglass fabric Unit 6 seal and 80 times that of the factory splice. Similar results occur when compared to the Unit 7 seal. The new material is three times as strong as the unspliced Unit 7 seal material and fourteen times as strong as the factory splice

in the Unit 7 seal. The new material has five times the elongation of the unspliced Unit 7 material and sixty times the elongation of the Unit 7 splice. The new seal material of polyester fabric reinforced silicone rubber also cannot have any flaws in the fabric material because of the nature of the component materials and the differing manufacturing method. Therefore, the new polyester fabric reinforced silicone rubber seal material is far superior to the fiberglass fabric reinforced rubber material used in the Unit 6 and Unit 7 PRD contraction joint seals which ruptured during the May 1990 as found pressure test.

5.0 CONCLUSIONS

Failure of the fiberglass fabric reinforced silicone rubber seals at the Unit 6 and Unit 7 contraction joints in the Pickering NGS PRD during the May 1990 as found pressure test was due to the weakness of the seals at the factory splices. This weakness was due to subsurface manufacturing flaws in the fiberglass fabric caused by thermal stresses in the seal during the curing process. These flaws weaken the seal material by 80 to 90 percent and have been described in previous reports [1]. The failures may have been exacerbated by the aging process causing lack of flexibility in the silicone rubber and by stresses from previous pressure tests but these phenomena and their contribution to failure are not yet understood.

The replacement seal material of polyester fabric reinforced silicone rubber has demonstrably superior strength and flexibility characteristics over the old Unit 6 and Unit 7 fiberglass fabric reinforced silicone rubber contraction joint seals. Furthermore, because of differing manufacturing methods and the nature of the component materials, the new seals cannot have manufacturing induced fabric flaws which would lead to reduction of strength as with the old seals.

6.0 ACKNOWLEDGEMENT

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7.0 REFERENCES

1. Lewak, R.J., "Pickering Ngs 'B' Pressure Relief Duct Expansion/Contraction Joints Seal Failures Investigation - Phase I," Chemical Research Department Report C88-37-K, July 6, 1988.

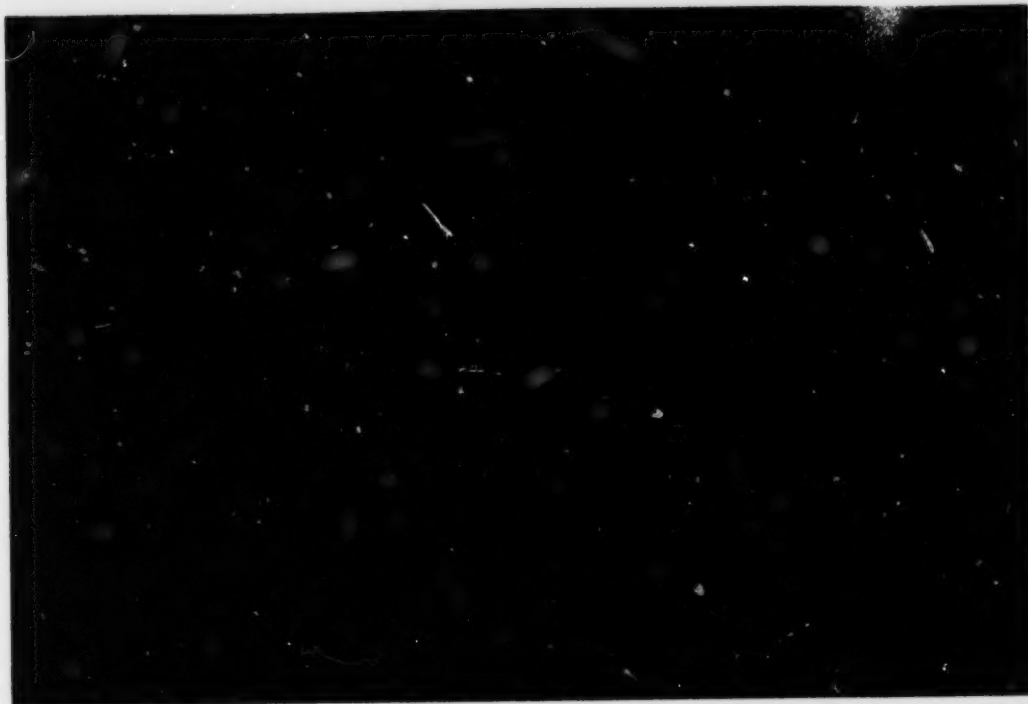


FIGURE 1 FAILURE IN FACTORY SPLICE IN PICKERING NGS PRD UNIT 6
CONTRACTION JOINT FIBERGLASS FABRIC REINFORCED
SILICONE RUBBER SEAL



FIGURE 2 CLOSE UP OF FAILURE IN FACTORY SPLICE OF UNIT 6
CONTRACTION JOINT SEAL

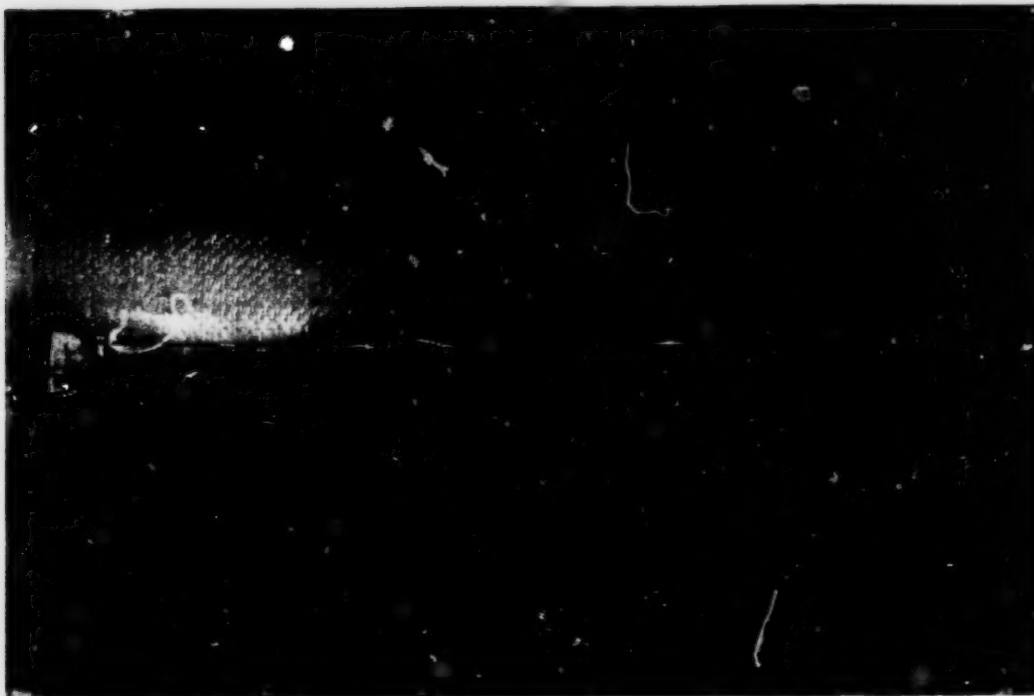


FIGURE 3 FAILURE IN FACTORY SPLICE OF PICKERING
NGS PRD UNIT 7 EXPANSION/CONTRACTION
JOINT FIBERGLASS FABRIC REINFORCED SILICONE
RUBBER SEAL



FIGURE 4 CLOSE-UP OF FAILURE IN FACTORY SPLICE
OF UNIT 7 CONTRACTION JOINT SEAL

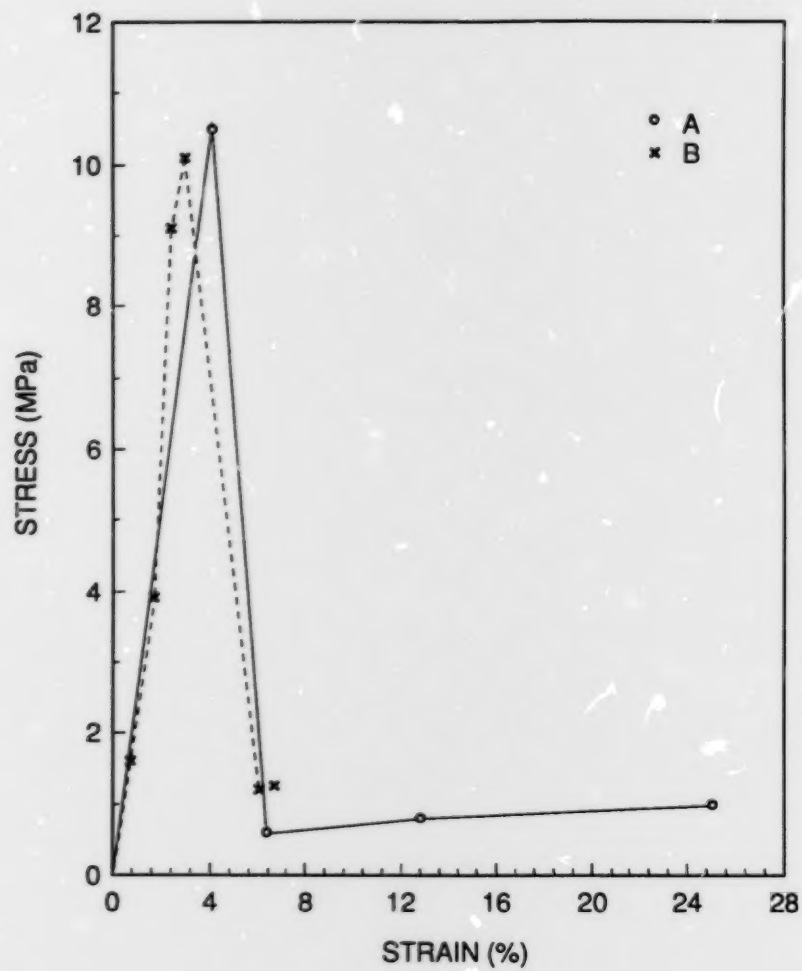


Figure 5 Stress-Strain Curves for Non-Spliced Unit 6 PRF Seal Specimens A and B

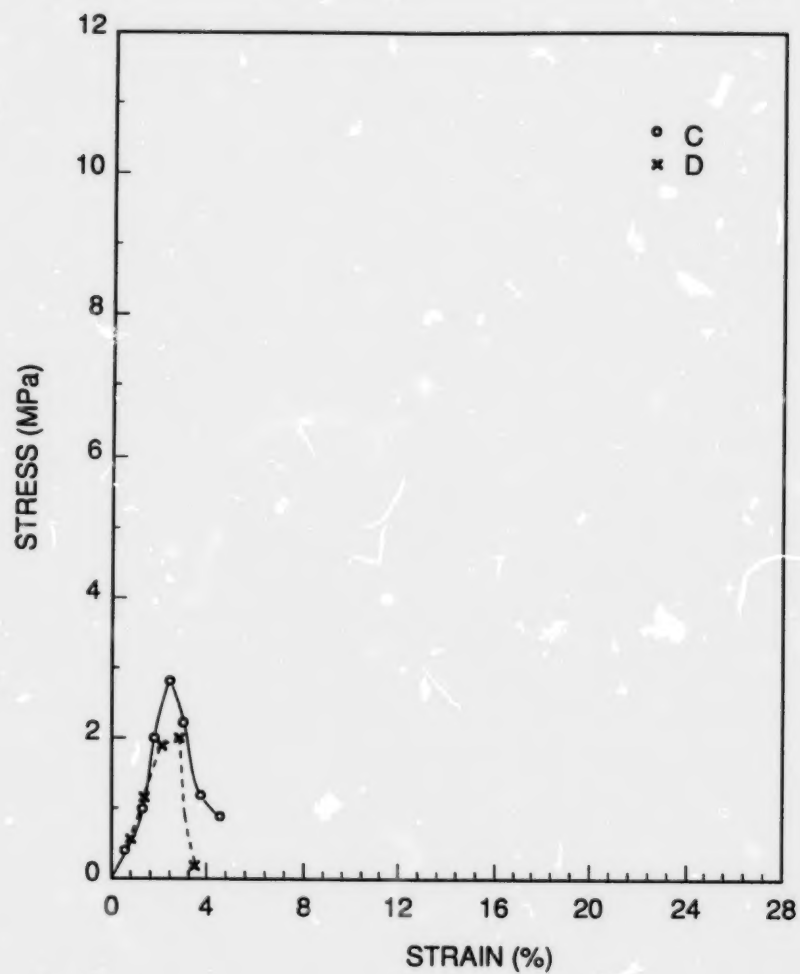


Figure 6 Stress-Strain Curve for Specimens C and D from Factory Splice of Unit 6 PRF Seal

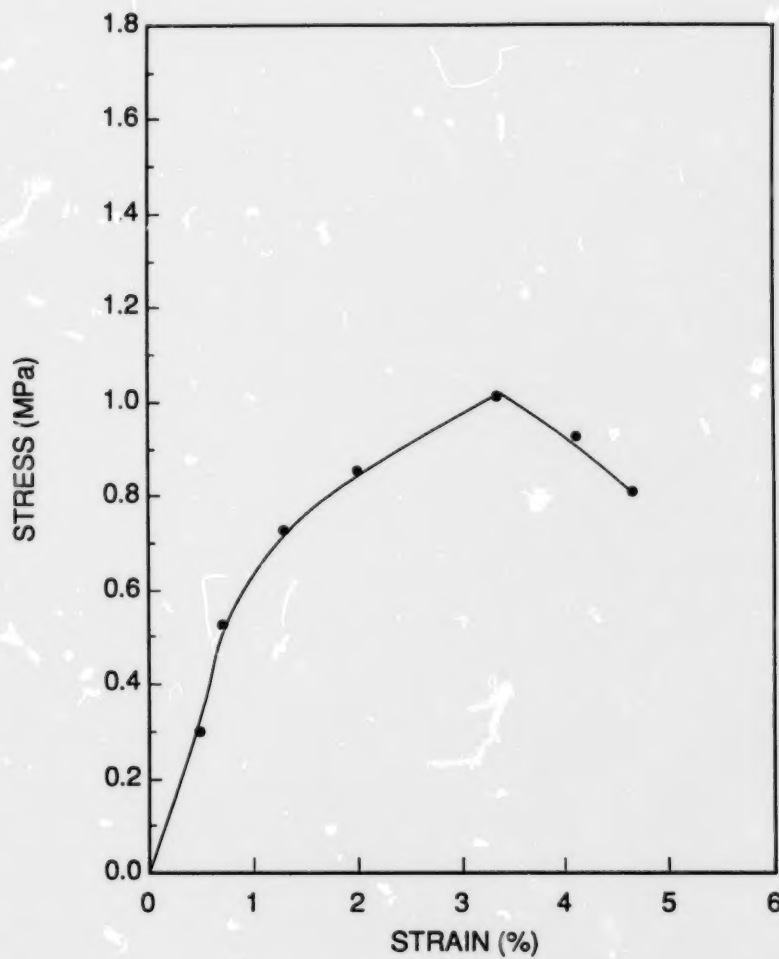


Figure 7 Stress-Strain Curve of Specimen 1
Factory Splice from Unit 7 PRF Seal

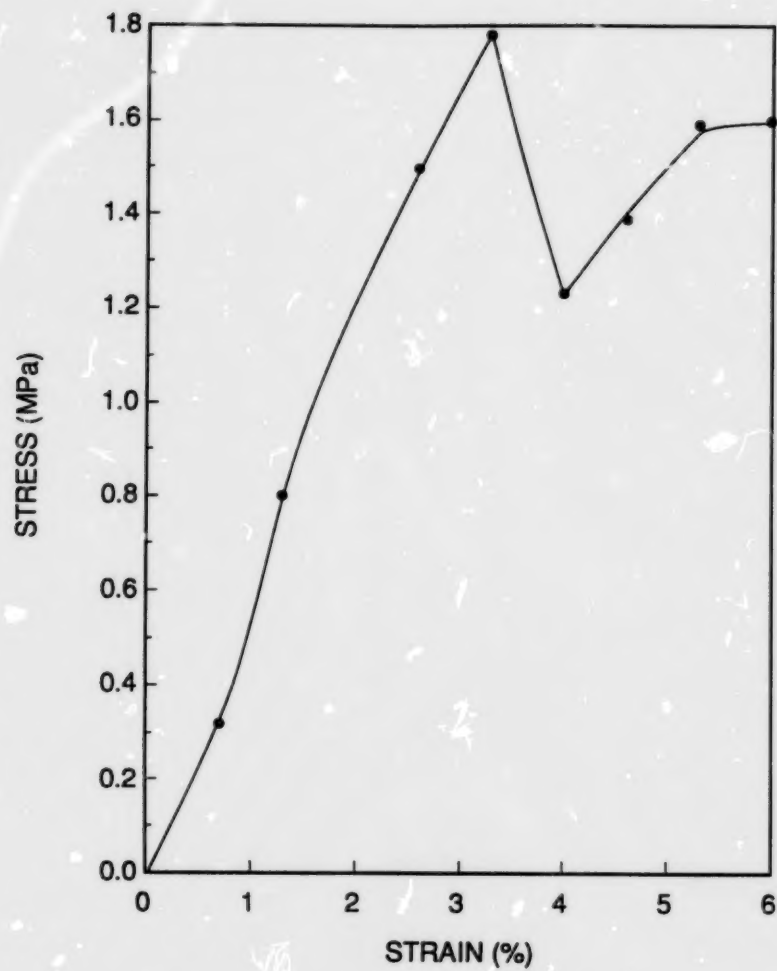


Figure 8 Stress-Strain Curve for Specimen 2
Factory Splice from Unit 7 PRF Seal

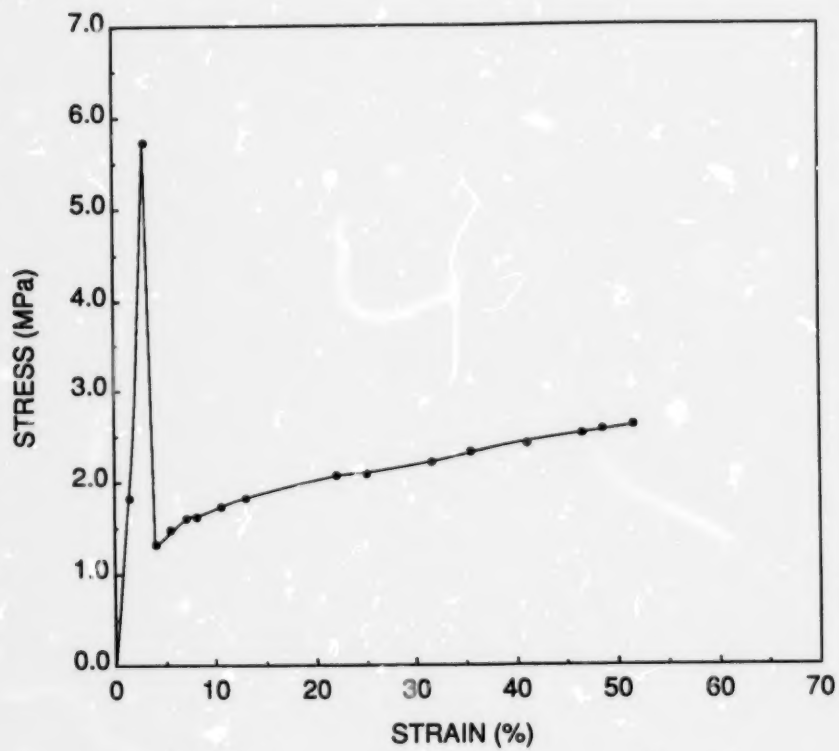


Figure 9 Stress-Strain Curve for Specimen 3
Non Spliced Specimen from Unit 7
PRD Seal

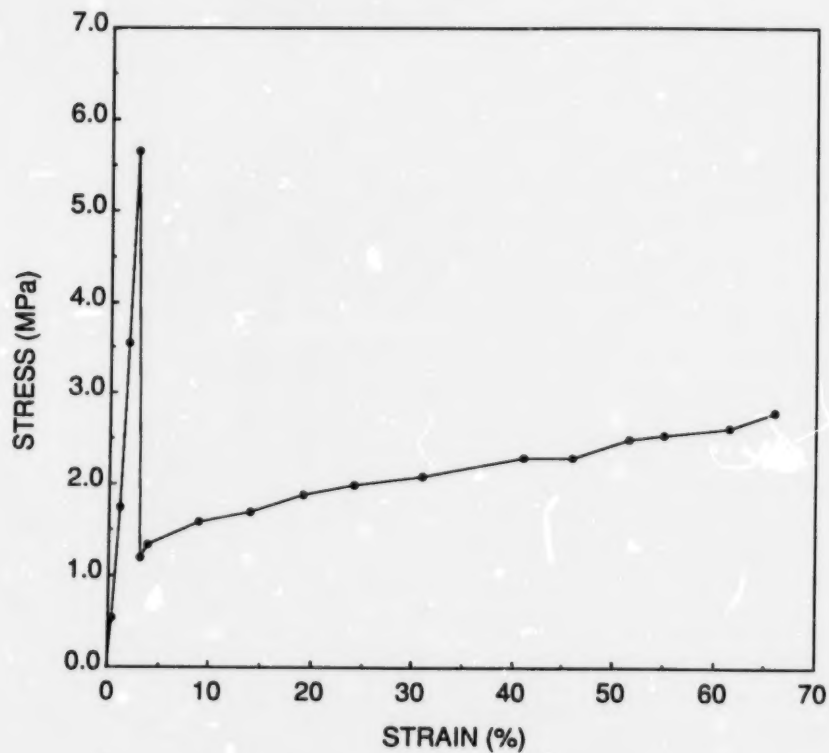


Figure 10 Stress-Strain Curve for Specimen 4
Non-Spliced Specimen from Unit 7
PRD Seal

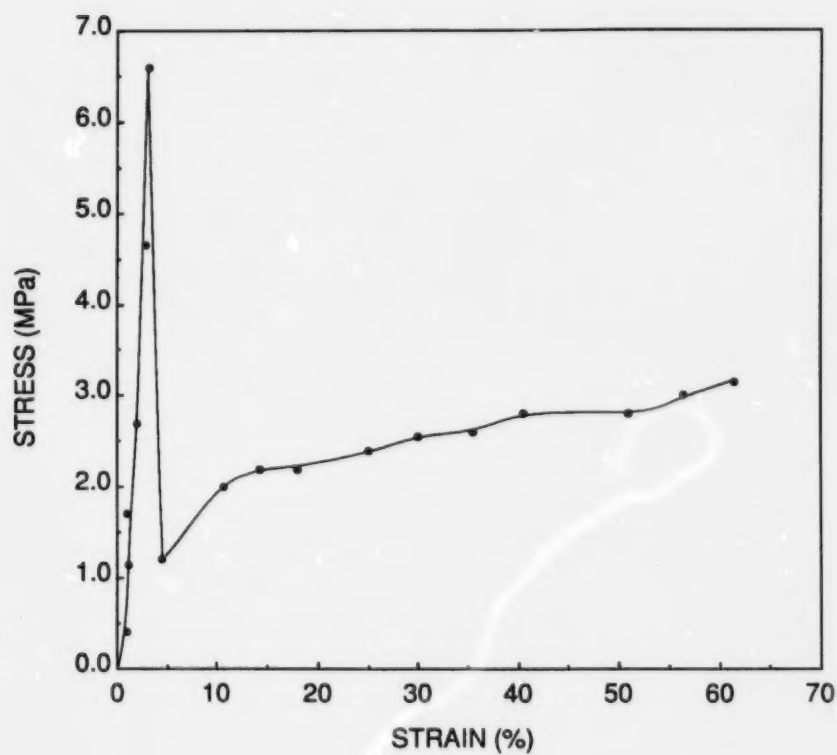


Figure 11 Stress-Strain Curve for Specimen 5
Non-Spliced Specimen from Unit 7
PRD Seal

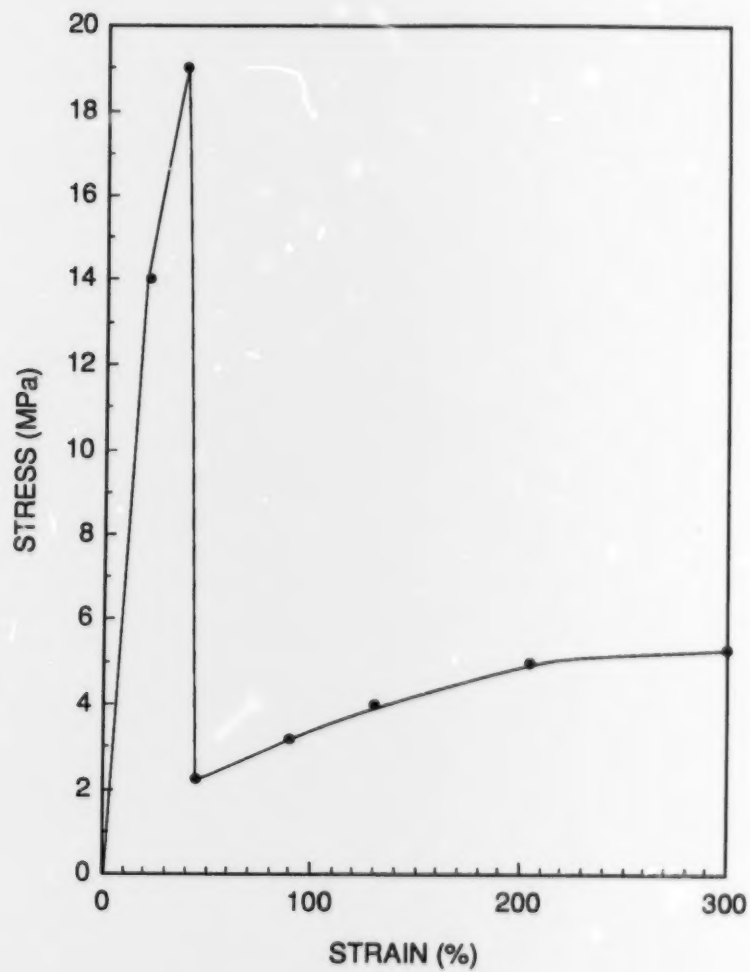


Figure 12 Stress-Strain Curve for Replacement
PRD Seal Material. Polyester fabric
Reinforced Silicone Rubber